James A. Baker III Institute for Public Policy
Rice University

The Legacy of Uranium Mining on the Coastal Plains of Texas

by

Ronald Sass, Ph.D.

Fellow in Global Climate Change
James A. Baker III Institute for Public Policy
Rice University

and

Cylette Willis, Ph.D.

Online Education Program Director
Digital Teaching and Learning
Rice University

December 5, 2013

Introduction

In the relatively unlikely event you find yourself in Falls City, Texas, I urge you to consider taking a ride down Farm to Market 791 W southwest of town. The smooth asphalt road follows gently rolling hills typical of the area and gives a pleasant drive.

Scenery includes well-farmed fields interspersed with stands of mesquite, post oak, live oak, and pecan trees, along with the usual roadside cactus and brush. The occasional farmhouses are generally neat and well maintained. Diversified farming is the rule, with grain, corn, sorghum, hay, and vegetables as the main crops.

About eight miles out of Falls City, the road intercepts Farm to Market 1344. You will want to turn right. In less than a mile, a massive mound of grayish-white loose stone looms in front of you on the left side of the road. The unexpected stone pile might first strike you as a supply of cobble for some misplaced ancient Roman roadbed. On closer inspection you realize that it is a purposively and carefully constructed edifice. Yet you can't help but wonder what it is doing here and what purpose it serves. It is too new looking to be the work of some ancient undiscovered civilization.

If you could measure its dimensions you would find it to be a rectangle approximately 2,200 feet by 2,600 feet and rising approximately 62 feet above the surrounding terrain (DOE 2008). You might be inclined to climb to the top for a closer look. After all, it is the height of a six-story building and should offer a great view of the countryside.

Looming in a grassy field, set back several feet from the road, the mound is protected behind a five-strand barbed wire fence. A large vehicle gate is available but it is securely locked. Before attempting to climb over the fence to scale the mound, it might be worthwhile to read one of the signs that are regularly positioned on fence posts along its whole perimeter.

There are 64 perimeter signs mounted on steel posts approximately at 500-foot intervals. Each sign is 24 inches wide and 18 inches high. The international symbol for radioactive materials is prominently placed on each sign warning of a potential hazard. Black lettering on a yellow

background states that the site is a uranium mill-tailing repository, it is U.S. government property, and no trespassing is allowed (DOE 2008).

Having easily suppressed any desire to scale the mound, you perhaps will instead continue to walk along the fence. If you do, you will encounter a monument of unpolished granite just inside the entrance gate at the east corner of the site. There is actually a second identical monument at the crest of the mound, or as we can now call it, the disposal cell. But this one cannot be seen without climbing to the top. These monuments are embedded in concrete, giving a hopeful feeling of longevity. The inscription consists of a diagram showing the site boundary and location of the cell, its date of closure (February 9, 1994), the quantity of waste tailings (7,143,000 dry tons) and the level of radioactivity within the disposal cell (1,277 curies of radium 226) (DOE 2008). What it does not state is that this mound was built by the U.S. Department of Energy with the intent of remaining sealed and intact, guarding the world against the contained radioactivity for a proposed period of 1,000 years. Considering that the half-life of radium is 1,690 years and that the cell contains uranium continuously decaying into additional radium, even 1,000 years is not enough time to render the mound's contents safe for exposure. In light of the condition of other constructions dating from 1,000 years past, the government, or someone as yet unknown, has a formidable maintenance job for a long time to come.

This location is officially known as the Falls City Uranium Mill Tailing Disposal Site. It is historically recognized as the Susquehanna Western uranium-processing mill. It was formally one of the busiest uranium producing mills in Texas. Now it stands as a testimony of man's attempts to put the world back the way he found it—before the uninhibited and unregulated hunt for nuclear energy and power. Its story, as well as that of uranium mining in Karnes County, can be traced back to the very beginnings of the discovery of uranium ore in Texas.

Is Uranium Really Mined in the Coastal Plains of Texas?

Few people outside of the nuclear industry and local folks are aware that minable deposits of uranium exist on the Coastal Plains of Texas. But uranium-mining activity has been taking place there alongside cattle and oil production for over half a century. In fact, during the 1970s, when

uranium was enthusiastically mined throughout the world to feed the Cold War, exploration for uranium extended over 200 miles in a narrow strip from Gonzales County east of San Antonio to Duval County in South Texas. Total exploration and development of uranium deposits in Texas ranked third in the nation. While uranium prices were at a maximum, Texas land held for uranium activity increased to 622,000 acres and extended to the Mexican border. By 1980, Texas ranked fifth in the nation in uranium output with an annual production of about 5.4 million pounds of yellow cake (uranium concentrate) per year (Eargle and Kleiner 2012).

Uranium deposits have been found in various locations across the Texas coastal plain, in the Panhandle and High Plains, and in volcanic rocks of the Trans-Pecos. Currently uranium is mined only in geologic formations along the south Texas coastal plain. This area includes the Carrizo, Whitsett, Catahoula, Oakville, and Goliad Geologic Formations. These formations are layered in several thousand feet of stacked sedimentary deposits and aquifers dating back from the Mid-Cenozoic (35 million years) to recent age. The ore-bearing formations of South Texas are most often composed of stacked layers of fine-to-coarse sand and sandstone separated from one another by relatively impermeable layers of clay, shale, or silt.

The sediments making up these formations were carried to present locations by large systems of meandering and braided rivers that flowed across the flat northwest coastal plain to the Gulf of Mexico during the Eocene to Miocene ages, 6 to 55 million years ago. As the sediment accumulated, it formed layers of intermixed sheets and tabular-shaped deposits. Since the area had little variation in elevation, rivers tended to be rather shallow and wide. Fine-to-coarse sand was deposited in these riverbeds. Occasionally the rivers would flood, bringing large quantities of silt and clay sediment that was deposited over the vast areas of the plain outside of the existing riverbed. Through geologic time, the rivers switched channels back and forth across the coastal plain. Such periodic changes in the flow of the rivers eventually caused the layering of channel fill sand and flood plain clay, silt, and shale that characterize these formations.

Uranium occurs naturally within the rocks that form the Earth's crust, particularly in granite, volcanic ash, and volcanic lavas. Some deposits occur as uranium-rich veins that formed from granitic magmas, but other deposits formed when oxidizing groundwater leached uranium from igneous rocks and transported it to reducing environments where uranium precipitated and

became concentrated, sometimes hundreds of miles from where it originated. In this way, volcanism near Big Bend National Park, Texas, and Mexico provided uranium for the Texas Coastal Plain deposits.

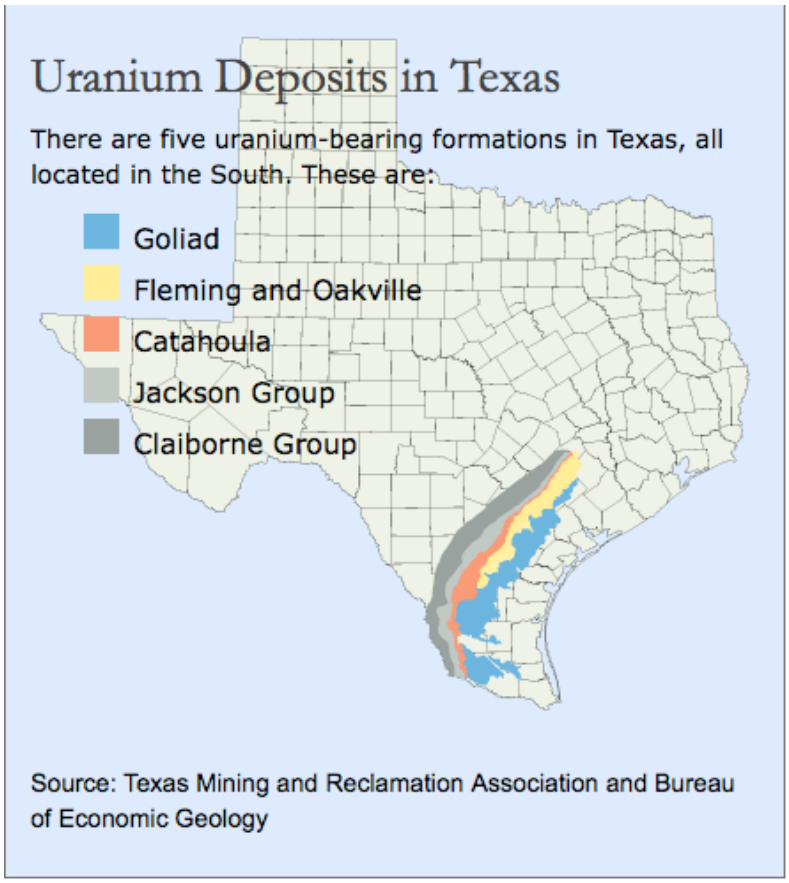
The characteristic "roll-front" deposits of uranium found along the Texas coastal plain are aquifer-controlled ore bodies that formed in medium- to coarse-grained sandstone. Oxygen-rich groundwater leached uranium from its source rock in the Trans-Pecos millions of years ago and carried it through sandstone until it reached an oxygen poor or reducing environment on the coastal plains. There it precipitated as uraninite or uranium oxide. An abundance of organic material or petroleum seeps along faults, or a deposit of sulfide mineral in the sediment, can create a reducing environment. Uranium precipitates in any available rock pore space at the interface between oxidizing and reducing conditions, often forming a curved roll-front ore body. This reduction/oxidation front can migrate over time, creating an ore trend that extends for miles. Numerous ore bodies are sometimes stacked parallel to one another at intervals along this trend, reflecting preferential flow paths in the aquifer. Roll-fronts are the predominant uranium deposit in the Coastal Plain. The South Texas coastal uranium-bearing formations are illustrated in the map in Figure 1.

A Brief History of Uranium Mining on the Texas Coastal Plains

Prior to the development of the atomic bomb, uranium was not an important metal on the international market. Nearly 80 percent of the minimal amount of uranium that was produced in 1939 came from a mine at Shinklolobwe in the Belgian Congo. With war in the offing, even that mine was closed so that the miners could be transferred to the more strategically important neighboring copper and cobalt mines. However, as the possibility of developing an atomic super-bomb became more and more promising, the demand for uranium became a priority of the United States and Great Britain as well as Germany. The race to win the war was on and uranium would decide the outcome. During the 1940s and early 1950s the United States government, along with that of the United Kingdom, attempted to gain control of the world's uranium supply in order to prevent other countries from developing and building an atomic bomb. Fortunately, this tactic worked well against the Germans and the Japanese, but may very well have been a

major factor in the development of the Cold War with the Soviet Union after the end of World War II (Helmreich 1986).

Figure 1.



During the early development of the atomic bomb by the Manhattan Project, the United States government purchased uranium from the Belgian Congo. Later uranium was obtained from vanadium mines in the American Southwest and Canada. The Canadian company Eldorado Mining and Refining Limited provided a large stock of uranium that was originally generated as waste from its radium refining activities.

After the end of World War II the development of nuclear power as well as the continued stock piling of atomic and nuclear bombs set off a worldwide search for additional uranium. It soon became evident that uranium was widely—if sparingly—distributed, and the idea of anyone

cornering the market became untenable. Currently approximately a dozen countries are actively mining substantial uranium deposits (IAEA 2009).

The first global "boom" in uranium exploration and mining was between 1956 and 1960. Demand was high as more and more countries developed nuclear power. Shortly before this time, uranium had been accidentally discovered on the Texas Coastal Plains. Late in the fall of 1954, G. H. Strodtman, while conducting an aerial radiometric survey in search of oil for a San Antonio oil company, observed high radioactivity in Eocene and Miocene formations near the now abandoned town of Deweesville in western Karnes County. Deweesville was southwest of the current town of Falls City. Although the presence of uranium in this area was not anticipated, this discovery very soon led to a stampede of prospectors who bought up leases and started mining exploration.

By the summer of 1956, about 15 uranium-mining prospects had been identified between the Rio Grande and Colorado Rivers. The first large-scale mining operation in Texas was initiated just west of Deweesville in Karnes County. By late 1960, the San Antonio Mining Company had mined and was ready to process 100,000 tons of low-grade ore. During that same year, the Atomic Energy Commission (AEC) and Susquehanna Western reached contractual agreement to build a 200-ton uranium (U) per day processing mill. The mill was built for $2 million and by 1961, was ready to accept ore for refinement into yellow cake or uranium oxide. Using an acid-leach extraction process, the mill started production of yellow cake that assayed approximately 78 percent uranium oxide, U_3O_8 (Eargle and Kleiner 2012).

The incentive to mine uranium during these early years was determined by the customer, namely the United States government in the form of the AEC. The AEC was not a perfectly well-behaved customer. In the early fifties the government provided assistance to prospectors by building access roads, assisting in drilling activities, and providing convenient assaying and ore buying stations. By the mid to late fifties, there were so many new mining discoveries in the nation that the AEC attempted to limit growth. On October 28, 1958, the AEC announced, "It is no longer in the interest of the government to expand the production of uranium concentrates." The first uranium golden age ended on November 24, 1958, when the AEC restricted its new

contracts for 1961 through 1966 only to those ore reserves that were already proven (Odell 2000).

Initially the AEC was the sole customer for Texas uranium ore. The Susquehanna Company and the Western Nuclear Company developed their mill under a purchase agreement with the AEC with uranium oxide (U_3O_8) to be bought for $9.90 per pound. This price was in effect from 1960 to 1962. The second agreement between the mill and the AEC was for $8.00 per pound and was in effect from 1962 through 1966. During these years, the Texas mill was the smallest of 17 processing units across the United States. From 1967 to 1970 the AEC began what was referred to as a "buying stretch-out" program that did not include Texas, causing the Susquehanna-Western mill to temporarily suspend operation (Charbeneau 1984).

As demand for uranium by the federal government waned, demand by private power companies increased. The world's first nuclear power plant, the USSR's Obninsk Nuclear Power Plant, came on line on June 27, 1954 (IAEA 2004). It was followed on October 17, 1956, when the Queen of England opened the Calder Hall nuclear power station in Cumberland. It was the world's first commercial nuclear venture (BBC News 2006). The U.S. Navy had been developing nuclear power as part of the nuclear powered submarine program. This resulted in the commissioning of the USS *Nautilus* in 1954. But the first American commercial nuclear power plant did not come on line until May 26, 1958. This was the Shippingport Atomic Power Station on the Ohio River in Pennsylvania.

Because of this new market for uranium ore, exploration in South Texas expanded again, along with that in other western states. New mining activity in Karnes County during the sixties was paralleled by a flurry of activity in several other counties along the Texas coastal plain. Although all mining in Texas between 1961 and 1967 had been by the Susquehanna-Western interests, by the fall of 1966 other companies were actively drilling exploratory wells and pursuing leases (Eargle and Kleiner 2012). Tenneco Minerals began mining in 1969 at a site 4.5 miles south of the Susquehanna-Western mill. An exact history of this period is not readily available because the industry was not highly regulated and because many small and unknown companies were involved in mining activities. However, it is known that all new mines developed by 1970 were

shallow open-pit surface mines and were sending ore to mills for processing. In 1968, for example, Susquehanna-Western's mill in Karnes County processed an estimated 1.2 million pounds of U_3O_8. Eventually three such mills were operating in Karnes and Live Oak counties, processing ore from mines such as Susquehanna, Conquista JV, and Chevron even though the price for uranium oxide had dropped to between $5.50 and $6.00 (Odell 2000).

The period from 1970 to 1980 was again one of rapid expansion fueled in part by the AEC partially releasing market controls on the price of uranium ore and also relaxing restrictions on its sale to an increasing number of nuclear power plants operated by private utilities (Larson 1978). Early in the decade, Union Carbide initiated a new form of mining uranium, in situ leaching or ISL, at Palangana Dome. Subsequently, Susquehanna-Western constructed an additional mill for high lime ores at Ray Point. A joint venture between Pioneer Nuclear and Continental Oil, the Conquista open pit, commenced production at the same time (Odell 2000).

The development of in situ leaching (ISL) was of major importance to the rejuvenated uranium-mining industry. ISL is a method for extracting uranium ore from the ground by dissolving the ore in place and removing it through extraction wells rather than by open-pit mining practices. This procedure offers the prospect of the production of ore a quality similar to open-pit mining, but at a cheaper cost and from deeper ore bodies. The process also poses less danger from radioactivity during mining because the overburden need not be removed and does not leave behind piles of radioactive tailings. The method was developed by the Utah Construction and Mining Company at its Shirley Basin site in Wyoming during 1961 to 1963 and put into production from 1963 to 1969. This method reached full stride in Texas in 1975 when Atlantic Richfield, U.S. Steel, and Dalco piloted an in situ plant at the Clay West site near George West in Live Oak County (Charbeneau 1984). In April the mine began operation at a production rate of 250,000 pounds per year. A second in situ mine was permitted in October 1976. By December of the same year, the U.S. Steel Burns Ranch operation in George West, Texas, began production at a rate of 150,000 pounds per year (Odell 2000).

Uranium mining in Texas during the late 1970s utilized both open-pit and in situ methodologies, but in situ mining would soon become the predominate choice of operation. Texas then led all

other states in the amount of ore produced by in situ leaching. By 1980, nine companies were using in situ technology at 25 sites located in Bee, Duval, Karnes, Live Oak, and Webb counties (Charbeneau 1984).

Uranium-mining production in Texas today is tied closely to the uranium spot market price, even though both the government and the utility companies favored multi-year contractual arrangements. During the early years of the 1950s, Texas uranium mining was both encouraged and stabilized with a fixed selling price mandated by the Atomic Energy Commission. The ore was close to the surface and therefore easily mined by open-pit methods. New mines could be explored, developed, and in production in a very short time since both federal and state regulations were lax to nonexistent. As nuclear power plants came on line, the utility companies favored supply contracts that were long-term and thus ensured a constant and steady stream of fuel. For the next 15 or so years, the price of uranium slowly dropped as more and more nuclear power plants requiring more and more uranium were over-supplied by more and more uranium mines and mills. The 1970s unfolded with an increasing abundance of new civil nuclear power plants, accompanied by the global oil crisis of 1973. Both events encouraged stock piling of uranium and the price of uranium rose. The result was a strong bull market that encouraged more and new uranium ore production. The price of uranium went from $8 per pound in 1970, $10.50 in 1975, and $22 in 1976 to over $43 in 1978 (Charbeneau 1984).

With stockpiling common, a perceived shortage of supply encouraged accelerated exploration and development of new mines in South Texas as well as the rest of the world while utility inventories grew steadily. By 1979, production exceeded consumption as a uranium economic bubble formed. Then, on March 28, 1979, the Three Mile Island power plant in Pennsylvania suffered a partial nuclear meltdown, releasing a small amount of radioactive gases and radioactive iodine into the environment. The accident gave voice to anti-nuclear safety concerns among members of the general public, resulting in a significant turning point in the global development of nuclear power (Fisher 1997). Whereas uranium ore sold for $43.25 in December 1978, the price dropped to $40.25 by December 1979 and continued to drop, reaching $23.50 by September 1981 (Charbeneau 1984). The price continued to slowly but steadily decline until it

reached a low of $7.10 per pound of U_3O_8 in December of 2000, a value close to the prior all time low of $7 reached in November 1991.

The uranium spot price began to recover with the beginning of the new millennium—$9.60 in 2001, $10.20 in 2002, $14.50 in 2003, $20.70 in 2004, and $70.20 in 2006. By November of 2007, it had reached an unprecedented high spot price of $136.00. Then, during the course of 2008, the uranium spot price declined from $90 to $53 per pound where it stabilized. (Ux Consulting 2012; Wise Uranium Project 2012). Recently (June through September 2013) the price was stable at around $35 per pound of U_3O_8.

Open-pit and In Situ Uranium Mining

In all uranium-mining operations, the ore body must first be discovered. It is then characterized in terms of areal extent, depth, and grade, usually by drilling exploratory wells and logging them. Uranium deposits in the Texas coastal plains generally are in Eocene (56 to 34 million years ago) sedimentary rock. As early ore deposits were close to the surface (100 to 400 feet depth), extensive exploratory drilling was easily accomplished and ore bodies were relatively easily found. By 1970, according to the Atomic Energy Commission, Texas uranium reserves totaled 6,622,323 tons of ore averaging 0.16 percent U_3O_8 (Eargle and Kleiner 2012).

A play is a geological term signifying a group of potential mine fields or prospects in the same region that are controlled by the same set of geological circumstances. Typical uranium plays were a few hundred feet wide and of the order of 100 feet deep in ore extent. Early Texas uranium mines used open-pit technology. The overburden was no deeper than 300 feet in Karnes County and was simply dug out, exposing the ore-bearing layer. Most of the open-pit uranium mines operated in Karnes County with some activity in Gonzales, Atascosa, Live Oak, and McMullen counties.

Some open-pit mines processed their own ore by heap leaching. In the heap leaching process, the ore is placed in a “heap” on an impervious pan of plastic, clay, or asphalt. Perforated pipes are placed under the heap for draining purposes. An acidic solution is sprayed over the ore,

dissolving the uranium. The uranium-enriched solution drains into the perforated pipes and is collected and transferred to an ion-exchange system. The ion-exchange column extracts and concentrates the uranium ore, producing yellowcake (relatively pure uranium oxide). The spent solution is generally discarded into an evaporation pond or a deep well. The yellowcake is transported to a secondary processing plant for further purification and enrichment. The extracted "heap" or tailings containing uranium and radium (both radioactive and toxic) were sometimes returned to the mine pit and abandoned.

Most open-pit ore bodies were excavated and trucked to a nearby mill. Open-pit mining began in 1959. Remember the Susquehanna Western Incorporated (SWI), the mill under the mound where this story began. Built in Karnes County in 1961 and operated until 1973, it employed a sulfuric acid process to leach the ore. The mill extracted approximately 700 tons of uranium oxide or yellow cake from approximately 2.5 million tons of ore and generated a total of 3.1 million tons of tailings and waste solutions during its lifetime (DOE 1991). Tailings and waste solutions were impounded in seven settling ponds, four of which were formerly open-pit mines. The ponds were 30 to 35 feet deep and unlined except for naturally occurring clay-rich soils and sedimentary rocks (DOE 2008). The handling of radioactive waste by SWI was typical of all mills at the time and posed serious threats of soil, air, and water (both surface and ground) contamination.

By 1971, the Continental Oil Company (CONOCO) and Pioneer Nuclear Corporation initiated the Conquista project to mine uranium in Karnes County. A mill was built as part of the project to process 1,750 tons per day of ore from open-pit mines within a thirty-five mile radius of the plant. At approximately the same time Susquehanna-Western began operation in a new 1,000-ton-per-day uranium mill at Ray Point in Live Oak County. By 1975, these mills were processing the product of open-pit mines in Karnes and Live Oak counties (Eargle and Kleiner 2012).

In the same year, Atlantic Richfield Company completed construction of the Clay West uranium recovery plant near George West in Live Oak County, Texas. This plant incorporated the first commercial in situ uranium solution recovery mine in Texas. This new form of mining was soon to essentially replace open-pit operations. Two major factors favored in situ mining over open-pit surface mining when it was introduced in 1975. Typically the lead time necessary to complete

exploration, permitting, and developing for an open-pit mine was approximately seven to 10 years, whereas these processes for an in situ mine could be completed in only two to three years of lead time. So a company was able start realizing a return on investment much earlier using the new technique. This advantage is particularly important to a smaller company or one with limited resources and encouraged many underfunded companies to enter the business. Also during actual mining of ore, the cost of producing yellow cake in the late seventies was estimated to be $11.83 per pound by conventional open-pit mining compared to $8.73 per pound by in situ mining (Charbeneau 1984). Thus a company could realize a bigger margin of profit using ISL technology.

A relaxation in regulation plus the promise of quick profits attracted smaller mining companies, many of which were underfunded, lacking in mining skills and impatient for profits. By the mid-seventies, Texas ranked second in the nation in drilling for uranium. The Texas uranium belt was peppered by 22 drilling rigs and 10 logging units, operated from Fayette County to Starr County. Over one million acres of farm and ranch land were under lease for possible uranium mining by 18 major companies and independent operators (Eargle and Kleiner 2012).

In situ leaching of uranium differs from open-pit mining by leaving the ore in the ground and extracting the uranium in situ. The recovery of uranium and other minerals is accomplished by dissolving them in an injection delivered solvent or lixiviant. Consequently there is little surface disturbance, and the tailings and other waste are left in the ground. ISL uses large amounts of water, usually the groundwater of the ore layer. The water is mixed with an oxidant such as oxygen or a peroxide and a complexing agent that aids in dissolving the uranium (World Nuclear Association 2012). In early attempts at in situ mining, the leaching solution was usually a sulfuric acid solution. More commonly, the leaching solution consisted of groundwater supplemented with oxygen and/or hydrogen peroxide and bicarbonate, which is easier to control (NRC 2012).

The fortified water is pumped into the ore zone through a series of injection wells where the uranium is dissolved. The resulting uranium solution is then collected through a surrounding set of recovery wells and pumped into a nearby processing facility. There the uranium is

concentrated by an ion-exchange process, further purified, concentrated, and dried to produce yellowcake or uranium oxide (NRC 2012).

The Ebb and Flow of Regulation of Uranium Mining in Texas

In the Beginning

Prior to the realization of the potential military value of the fission ability of naturally occurring U235, uranium ore was either thought of as a source of radium, bright yellow pigment, or a waste byproduct of vanadium mining. Uranium first became critically important during World War II with the development of the Manhattan Project, which, of course, culminated in the explosion of two atomic bombs over Japan, ending the war in the Pacific. During this time, uranium-mining operations in the United States were primarily carried out in Colorado and tightly managed by the military. Only federal contracts for the purchase of uranium were possible, and they were initiated by the Army's Manhattan Engineering District from 1942 to 1946. The Atomic Energy Act of 1946 (revised by the Atomic Energy Act of 1954) established the Atomic Energy Commission and gave it regulatory authority over all radioactive materials, including purchasing power for Cold War weapons development. The AEC interpreted its jurisdiction to apply only after the mined ore was delivered to the processing mills, leaving regulation of mining operations quite ambiguous since the states did not have sufficient experience to allow them to effectively oversee the mining of radioactive material (DOE 1995).

After the discovery of uranium on the coastal plains of Texas in 1957, prospectors began to swarm over the area looking for this radioactive "gold." Serious mining began in the early 1960s. The first miners were often thrust into a situation where they were barely knowledgeable of what they were doing. An equally inexperienced state government could only loosely regulate the mining operations. Prior to and during that time, there was also a degree of federal governmental secrecy surrounding the mining and usage of uranium. In addition, the South Texas Uranium District was rather sparsely populated, and few people were aware of the mining activities taking place in remote parts of the area. Many of those who were aware did not yet understand the hazards that might be associated with the handling of uranium ore and its tailings. Conditions

were ideal for, if not industrial disaster, serious environmental mishaps and local public health problems.

In a paper presented at the 8th Annual South Texas Environmental Conference, Parker and Herbert (2000) state: "From 1960 until 1983, uranium mining within the Nueces (and adjacent) watersheds generated large-scale landscape impacts including open-pit excavation, overburden pile accumulation, drainage course alteration, and ground and surface water contamination." They continued by reporting that: "Uranium mining liberated arsenic (As), molybdenum (Mo), selenium (Se), and vanadium (V) to the nearby environment via wind and water. Pit dewatering impacted nearby drainages; stockpiled tailings eroded and acidic processing wastes leached from unlined mine pits. Livestock, grazing near uranium mines, were poisoned by excess molybdenum."

Jeff Sibley, a third-generation Texas rancher and president of the Texas Energy Alliance, has long been an outspoken critic of uranium-mining practices. Drawing on his personal experiences and that of his friends and neighbors, as well as studies of Texas state records, he wrote a very absorbing tale about the early days of mining that later appeared in *Uranium Mining in Texas* (ALTURA 2012). An excerpt from that document follows:

> During the early days of the nuclear age, little was known about the dangers of radioactivity. This was the "Cold War" era and the fear over national security was very real. In order to ensure the atomic bomb program, the federal government strictly enforced the National Security Act. This act stifled information and research on radiation health effects. A special branch of the federal government actively worked to defeat public lawsuits over nuclear issues. As a result, little information was available to the public. Under these conditions and with help from the government (and in some cases, the "front company" ownership by the government), the Texas mines prospered in secrecy for the first 26 years. Free from pubic scrutiny and government regulations, approximately 19 uranium strip mines operated in the state during this time. Very little is known about them.

> Over time, the general lack of concern by the industry for the dangers posed by radiation resulted in large-scale damage as the companies used the environment to work out their engineering kinks. These abuses increased until public outrage forced the state to pass legislation in 1975 that created government oversight of uranium mining in Texas. The law provided some very needed protection by establishing state agencies to oversee and regulate the industry, but it did not address any of the problems created by [the] mining. Instead the law required that the agencies figure out ways to deal with the problems. Unfortunately, by providing the specter of government oversight, the regulations served to pacify the public's concerns about uranium, which allowed the industry to continue to grow unabated.

Recent Regulatory Situation for In Situ Recovery Mines (1982-To Date)

Currently, the federal regulatory responsibility for uranium-mining operations depends on the method by which the uranium is extracted from the earth. In Texas, if the uranium is extracted by open-pit methods, regulation is by the Texas Railroad Commission as agreed upon by the U.S. Department of Interior Office of Surface Mining. On the other hand, the federal Nuclear Regulatory Commission (NRC) regulates all uranium mined by in situ recovery technology. The difference in regulatory agency is because in situ recovery involves chemically altering the uranium ore prior to extraction (thus being covered by federal law requirements pertaining to mining products rather than the natural ore), whereas in open-pit mining the ore is physically removed from the pit without alteration. The NRC also regulates uranium mills that accept ore from open pit mines because the milling process chemically alters the uranium ore.

In Texas, however, the NRC does not directly regulate active uranium recovery operations. Texas is what is called an Agreement State, meaning that the state has entered into an agreement with the NRC to have the Texas Commission on Environmental Quality (TCEQ) exercise regulatory authority over all operations that would otherwise be regulated by the NRC (NRC 2012b).

In 1982, the federal Environmental Protection Agency (EPA) authorized Texas' plan to implement provisions of the federal Safe Drinking Water Act. The Texas legislature adopted

Chapter 27 of the Texas Water Code to delegate to the TCEQ the statutory authority to approve ISL mining operations because it takes place within an aquifer where the uranium is located.
To complicate matters even more, regulation of an in situ leaching uranium mine in Texas is divided between the Texas Railroad Commission (RRC) and the Texas Commission on Environmental Quality (TCEQ). The Texas Railroad Commission has jurisdiction over exploration mining, where the ore is not yet transformed, while wells constructed for actual production and mining of uranium and restoration of the mining area after mining is completed are the jurisdiction of the TCEQ. Thus we have created a situation that is cumbersome at best and disastrous at worse.

Exploration activity involves the drilling of many wells within a potential production area. Core samples and/or logging data are taken from the subsurface for analysis and determining placement and concentrations of uranium. This exploration activity is accomplished by standard drilling practices much as that employed in drilling water wells. Generally the drill holes are less than 400 feet deep. The RRC has a variety of rules for identification of an exploration area and rules for speedy well plugging and appropriate handling of surface disposal of cuttings and drilling mud. After establishing a proposed area for mining, regulation jurisdiction moves from the Railroad Commission to the Texas Commission for Environmental Quality.

Before beginning actual mining, an operator must apply for and receive three regulatory documents from the TCEQ:

1. Class III Underground Injection Permit: In situ mining begins with the construction of a well to inject materials to dissolve below ground uranium. Such a well is designated a Class III well. A Class III permit authorizes the mine operator to construct and operate Class III injection and production wells for recovery of uranium beneath a specified permit area.

2. Aquifer Exemption: The Class III permit application includes a request for an aquifer exemption, an administrative order by the TCEQ establishing that the part of the aquifer

in which mining is to be conducted does not serve as a source of drinking water for human consumption.

3. PAA Application: An Application for a Production Area Authorization (PAA) is required to describe mining and restoration activities in the proposed mining area. The PAA generally includes: a mine plan with estimated schedules for mining and aquifer restoration, a baseline water quality table, a restoration table, control parameter upper limits, monitor well locations, and cost estimates for aquifer restoration and well plugging and abandonment.

The purpose of these three documents is to ensure that the mining activity will not harm any groundwater that is being used for drinking and that the mine area groundwater will be returned to its original condition. These requirements are seldom, if ever, met.

Inadequacies of Regulatory Activity and Effects on Groundwater

Let's return to the past for a few moments and attempt to sum up the uranium-mining activity that took place in Texas during the early rough and tumble years of hell-bent prospecting.

As previously mentioned, uranium mining in Texas dates to the fall of 1954 when high radioactivity was discovered in the aerial radiometric quest for oil near the now extinct town of Deweesville in western Karnes County. Just two years later in the summer of 1956 something on the order of 15 uranium prospects had been started along a 300-mile long, narrow strip extending from the vicinity of the Colorado River in Fayette County into Starr County to a few miles north of the Rio Grande.

The first large-scale mining began in July 1959 just west of old Deweesville, a town that is now extinct. By late 1960, a local subsidiary of Climax Molybdenum Company had stockpiled 100,000 tons of moderately low-grade ore, waiting for the construction of a processing mill.

The expected processing mill was soon built and operated by Susquehanna-Western, Incorporated. It started production of relatively impure "yellow cake" or uranium oxide in 1961 (Eargle and Kleiner 2012).

The original contracts with the Atomic Energy Commission were fulfilled during the spring of 1966, and the mill was temporarily shut down. But by June of the same year, it resumed operation under a new contract with the Atomic Energy Commission, and uranium mining was off to the races.

The 1970s witnessed an upsurge in mining activity. At that time, 22 drilling rigs and 10 logging units were operating from Starr County to Fayette County, a million acres of land were under lease, and 18 major companies and independent operators were involved in some phase of mining activities. At the same time, substantial increases in uranium prices occurred. Increased demand encouraged exploration, development, and expansion of facilities throughout the decade, as exploration for uranium extended from Gonzales County to Duval County. A new Susquehanna-Western 1,000-ton-per-day uranium mill at Ray Point began operation to take care of the expanded mining activity (Eargle and Kleiner 2012).

In 1975, over 90 percent of purified uranium oxide came from the Conquista mill that serviced 10 open-pit mines in Karnes and Live Oak counties. Atlantic Richfield's Clay West uranium recovery plant was constructed to the country's first commercial in situ uranium-solution mine. Union Carbide Corporation constructed uranium recovery facilities at its Palangana in situ leach project in Duval County, and Mobil Oil Corporation continued development work on its in situ leach project in Webb County. Total exploration and development gave Texas a ranking of third in the nation. In the 1980s a number of uranium deposits were discovered within a belt extending from the middle Coastal Plain southwestward to the Rio Grande. Expansion continued until decreased demand and a lower price of uranium brought a sharp decline in Texas operations after 1980 (Eargle and Kleiner 2012).

The years between 1970 and 1980 describe a transition from the older open-pit uranium-mining operations to the newer and cheaper in situ leaching process. Today, Texas uranium mining is

very nearly exclusively ISL technology. Although newer and less expensive, how good is this ISL technology compared to open-pit mining and how does it impact the environment? It appears that it will not lead to newer and bigger mounds like the Falls City Uranium Mill Tailing Disposal Site. The tailings never leave the ground of the mining site and never reach the processing mill. However, any time a naturally occurring substance is removed from the ground using an industrial process, some environmental impact should be expected. In the case of the open-pit process for mining uranium, the radioactive tailings and other by-products may need to be encased for centuries to protect humans and other organisms. In the case of the in situ leaching process for mining uranium, the leftover radioactive by-products are underground and out of sight. However, because of the nature of the genesis of the uranium deposits, these underground contaminants are left behind in the aquifer in which they were originally deposited. These contaminants will follow that aquifer's groundwater wherever it may flow.

Texas has been slowly but steadily producing uranium by the ISL method since the mid 1970s. In 2009, the United States Geological Survey (USGS) studied the effectiveness of the regulatory process on the effects of this method on the local groundwater. At that time (2009), there were only two active Texas mines, Mestena Uranium's Alta Mesa mine and URI's Kingsville Dome mine.

The USGS found that a total of 36 ISL mining sites were authorized from 1975 to 2009. Seven were never mined, one was a tailings project, and one was combined with another property. This results in 27 mines that were developed into 77 well fields and subsequently entered into production. Authorization to produce in each of these well fields requires, among other stipulations, the establishment of initial baseline and final restoration goals for the composition of the groundwater associated with the mine. That is to say that the quality of the groundwater at the mining site must be tested before mining commences and the groundwater must be restored to at least that quality after mining operations cease.

Baseline and "amended" restoration values are available at the Texas Commission for Environmental Quality for all 27 production mines. Working for the USGS, Susan Hall was given free access to the TCEQ records of these mines. The USGS investigation was responding

to a possible increased activity of uranium exploration and mining in Texas and was concerned by the number of applications for ISL mines to the U.S. Nuclear Regulatory Commission. They were particularly anxious about a widespread opinion that "Groundwater has never been returned to baseline at any ISL mine" (Hall 2009). What Hall, who has a doctorate in geology, found is important to all Texans concerned about the sustainability of our drinkable water supply.

Most of the time a uranium-mining company will report that their baseline groundwater tests show the aquifer groundwater in the proposed mine-area is so contaminated that it cannot be used for human consumption. These aquifers are then typically granted exemptions from the Clean Water Act by the USEPA. In Texas, over a quarter of the PAAs report baseline groundwater contaminated above the relevant maximum contaminant level (MCL) for arsenic, cadmium, lead, radium, and uranium. All PAAs show radium levels above MCL and 90 percent contain radium levels above MCL. Although it has been demonstrated that these baseline values are artificially elevated during testing and do not reflect the drinkability of the water before pre-mining prospecting activity perturbed it (Sass 2011), the reported values are nevertheless used to establish restoration concentrations for the aquifer groundwater. Even with these artificially high contamination levels, no mine—not just in Texas but also in the entire United States—has returned the post-mining groundwater to baseline for all required elements. For example, the USEPA established the MCL for uranium as 0.03 milligrams per liter. Ninety-five percent of Texas uranium-mining PAAs have a baseline value above MCL and 68 percent of Texas mines show a final restoration value for uranium above this MCL. The MCL for radium is 5 pico-Curies per liter in drinking water. All PAAs are characterized by baseline values and all post-restoration radium concentrations were reported to be above this MCL (Hall 2009). Clearly, there is a problem here. New ways must be found to obtain correct baseline values, particularly in the case of radium, and new technology must be developed to restore a spent mining site to its correct pre-mining state. It is unacceptable to allow uranium mining to be conducted in an aquifer when current practices will never be able to return that aquifer to its pre-mining state.

Uranium is currently mined at two locations in Texas, the Palangana Mine operated by Uranium Energy Corporation near Hobson and the Alta Mesa mine operated by Mestena Uranium near Alta Mesa. Both employ ISL technology, and both are compromising the groundwater of their

associated aquifers. Both companies will also claim that the aquifers in question were contaminated beyond human use by the minerals natural to the vicinity and that their mining operations will leave them no worse off than they otherwise would be. That is not true. (I don't think that even the USEPA believes that.) That which is being thought of as naturally occurring contamination actually entered the groundwater by the procedures used during exploration and establishing the baseline condition of the groundwater (Sass 2011).

Two operating mines may not seem enough to spoil many aquifers, but uranium mining in the United States is currently in a relatively quiet period. The demand for uranium to operate power plants is being largely supplied by Russia as it decommissions its bombs in compliance with treaties with the United States. Unless additional treaties are forged, this source is due to end in late 2013. In addition, uranium is now selling at a market price of around $40 a pound, not enough to encourage much mining activity. However, as demand rises along with the market price, Texas is getting ready to ramp up. The Railroad Commission has 14 active exploration permits from seven different companies to start operations in 10 counties. Several are on the verge of mining operations, as are several existing mines that have temporarily suspended operation. All are waiting for the price of uranium to jump up. As in the past, not all of the companies that will hop on the band wagon when it arrives will have the capital to mine in a manner that protects the environment or be willing and able to spend the necessary cash to restore the mine to its former condition. With Texas in an extended drought, we can ill afford to waste any water on mining activities that are by their very nature faulted.

The Need for Sustainability

The global procurement of major amounts of uranium was born during World War II in the urgency of the Manhattan Project and the desire of the United States to develop the atomic bomb before Germany was able to do so. The intensity and secrecy of the quest for ore as well as our inexperience in handling uranium inevitably led to mining practices that were not concerned with the collateral effects on the people and the environment in the mining region. Regulation of mining in the United States was by the federal government. It concentrated more on hiding the mining activity than the welfare of the mining areas and the local populations. Residents,

because they were unaware of what was taking place, were not in a position to police mining activities or protect their own health.

Uranium was not discovered in Texas until 1954, after the bomb was successfully developed, World War II ended, and the quest for uranium shifted to developing nuclear power for electricity and uranium for the bombs of the Cold War. However, as mining in Texas began, the urgency for uranium and the secrecy of the quest hardly changed. The Atomic Energy Commission regulated mining activities, the United States government was the sole purchaser of the produced uranium ore, and regulation remained relatively lax.

Over time, regulation slowly changed. Private commercial nuclear power plants began in the United States in the late 1950s, and the government allowed other customers for uranium. By act of Congress in 1974, the Atomic Energy Commission was replaced by the Nuclear Regulatory Commission. Eventually, the regulation of mining operations was partially delegated to the states. In Texas, the job fell to the Railroad Commission and the Texas Commission on Environmental Quality. Most importantly in terms of its effects on the environment, uranium mining shifted from open-pit operations to in situ leaching procedures, leading to new techniques based on evolving technologies. The demand for uranium followed the public perception of the danger versus the rewards of nuclear energy; the price of uranium naturally followed the demand. As the price of uranium rose and fell, so did the number and quality of the companies mining for it. Public interest in regulation ebbed and flowed. Regulation followed innovation but inevitably lagged behind.

Today, regulation of uranium mining in Texas is tied to technology that is decades old and outdated. Uranium is being produced—but when production is over and mining companies are required to return mining areas to pre-mining conditions, what then if not one Texas mine has been successfully restored. Particularly and most worrisomely, the groundwater that flows through the mining area has been rendered unusable for Texas' citizens, farmers, and ranchers. With mining regulations as they currently exist, it is probably impossible to restore the area to pre-mining conditions. The fact that regulations do not invoke the latest scientific knowledge that is available is, we believe, well known to the regulatory agencies, including the Environmental

Protection Agency and the Nuclear Regulatory Commission at the national level and the Texas Commission on Environmental Quality on the state level. We believe that they also know that in order to incorporate the latest science into regulations, additional experimental data on new mining techniques must be obtained and new methods of mining must be developed (Sass 2011). This requires mustering the time, money, and political will necessary to formulate new policies that do so. But unless it happens, uranium mining in Texas will continue to poison the groundwater and reduce the value of Texas land. This is ultimately a resource extraction issue and also a water issue. In the end, Texas leaders must find their way to crafting effective policy for both these interests that combines the challenging physical and political relationship between them.

The early uranium-mining business left visible scars—such as the barren fields and mining pits surrounding the central monument—to an industry gone crazy: the Department of Energy Falls City Uranium Mill Tailing Disposal Site. This time, unless mining practices change, the monument will not be visible. But it will be there, hidden underground in the various poisoned aquifers that will no longer be supplying the life-blood of Texas, drinkable water.

References

Beaman, M., and W.W. McGee. 2002. "Geodatabase of the South Texas Uranium District." *Gulf Coast Association of Geological Societies Transactions* 52: 39-42.

Charbeneau, R.J. 1984. "Groundwater Restoration with In Situ Uranium Leach Mining." *Studies in Geophysics: Groundwater Contamination*. Compiled by Geophysics Study Committee, Geophysics Research Forum, and National Research Council. Washington, DC: National Academy Press.

Eargle, D.H., and D.J. Kleiner. 2012. "Uranium Mining." *Handbook of Texas Online*. Accessed June 8, 2012. http://www.tshaonline.org/handbook/online/articles/dku01.

Fischer, David. 1997. *History of the International Atomic Energy Agency: The First Forty Years*. Vienna: International Atomic Energy Agency.

Hall, Susan. 2009. *Groundwater Restoration at Uranium In-Situ Recovery Mines, South Texas Coastal Plain*. U.S. Geological Survey Open-File Report 2009-1143. Reston, VA: U.S. Geological Survey.

Helmreich, J.E. 1986. *Gathering Rare Ores, The Diplomacy of Uranium Acquisition, 1943-1954*. Princeton, NJ: Princeton University Press.

International Atomic Energy Agency. 2009. *World Distribution of Uranium Deposits (UDEPO) with Uranium Deposit Classification*. Vienna: International Atomic Energy Agency.

Larson, W.C. 1978. *Uranium In-Situ Leach Mining in the United States*. Washington, DC: U.S. Department of the Interior, Bureau of Mines.

Odell, R.D. 2000. *Getting the Cake in the Can*. Wyoming Mining Association. http://www.wma-minelife.com/uranium/papers/histur.htm.

"On This Day: October 17." 2006. *BBC News*. Accessed June 11, 2012. http://news.bbc.co.uk/onthisday/hi/dates/stories/october/17/newsid_3147000/3147145.stm.

Parker, R.L., and B.E. Herbert. 2000. *History, Geochemistry and Environmental Impacts of Contaminants Released by Uranium Mining in South Texas*. South Texas Environmental Conference: Corpus Christi, TX.

Sass, R.L. 2011. *Uranium Mining in Texas: Why Is It Done That Way?* Houston: Rice University's Baker Institute.

Sibley, Jeff. 2012. *Uranium Mining in Texas*. Alliance of Texans for Uranium Research and Action. Accessed June 25, 2012. http://www.uraniuminfo.org/files/Sibley's Uranium Mining in Texas.pdf.

Sorenson, E. 2011. "Uranium is a lucrative investment proposition." *Unconventional Wisdom*. December 6. http://unconventional-wisdom.com.au/library/uranium-is-a-lucrative-investment-proposition/.

Staff Report. 2004. "From Obninsk Beyond: Nuclear Power Conference Looks to Future." International Atomic Energy Agency. Accessed June 11, 2012. http://www.iaea.org/newscenter/news/2004/obninsk.html.

U.S. Department of Energy. 1991. *Final Environmental Assessment of Remedial Action at the Falls City Uranium Mill Tailings Site, Falls City, Texas*. DOE/EA-0468. Albuquerque, NM: U.S. Department of Energy.

U. S. Department of Energy. Energy Information Administration. Office of Coal, Nuclear, Electric and Alternate Fuels. 1995. *Decommissioning of U.S. Uranium Production Facilities*. DOE/EIA-0592. Washington, DC: Department of Energy.

U.S. Department of Energy. Office of Legacy Management. 2008. *Long-Term Surveillance Plan for the U. S. Department of Energy Falls City Uranium Mill Tailings Disposal Site, Falls City, Texas*. DOE-LM/1602-2008. Grand Junction, CO: U.S. Department of Energy.

U.S. Nuclear Regulatory Commission. 2013. *In Situ Recovery Facilities*. Last modified May 24. http://www.nrc.gov/materials/uranium-recovery/extraction-methods/isl-recovery-facilities.html.

U.S. Nuclear Regulatory Commission. 2013. *Uranium Recovery*. Last modified November 13. http://www.nrc.gov/materials/uranium-recovery.html.

Ux Consulting Company. 2012. http://uxc.com.

World Information Service on Energy Uranium Project. 2012. http://www.wise-uranium.org/index.html.

World Nuclear Association. 2012. *In Situ Leach (ISL) Mining of Uranium*. Accessed June 18, 2012. http://www.world-nuclear.org/info/inf27.html.